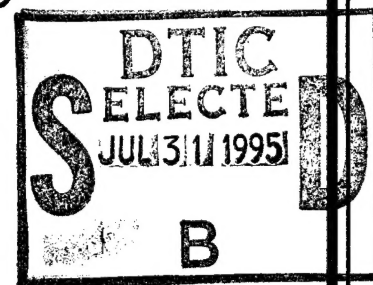


AL/CF-TR-1995-0095



**RELATIONSHIP BETWEEN AGE AND SUSCEPTIBILITY  
TO DECOMPRESSION SICKNESS: A REVIEW**

**Zahid M. Sulaiman, 2LT, USAF, BSC  
Andrew A. Pilmanis  
Robert B. O'Connor, Capt, USAF, BSC  
F. Wesley Baumgardner**



**CREW SYSTEMS DIRECTORATE  
Crew Technology Division  
2504 Gillingham Drive, Suite 1  
Brooks Air Force Base, TX 78235-5104**

**JULY 1995**

**Interim Technical Report for Period January 1994 - June 1994**

Approved for public release; distribution is unlimited.

**DTIC QUALITY INSPECTED 5**

**AIR FORCE MATERIEL COMMAND  
BROOKS AIR FORCE BASE, TEXAS**

**ARMSTRONG  
LABORATORY**

**19950728 065**

## NOTICES


When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the Government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder, or any other person or corporation; or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

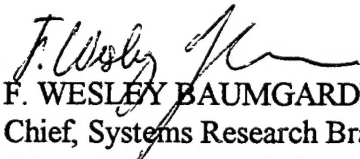
This report has been reviewed and is approved for publication.



ZAHID M. SULAIMAN, 2Lt, USAF, BSC  
Biomedical Engineer



ANDREW A. PILMANIS, PhD  
Chief, High Altitude Protection



F. WESLEY BAUMGARDNER, PhD  
Chief, Systems Research Branch



JAMES P. DIXON, Colonel, USAF, BSC  
Chief, Crew Technology Division

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE July 1995		3. REPORT TYPE AND DATES COVERED Interim January 94 - June 94
4. TITLE AND SUBTITLE Relationship Between Age and Susceptibility to Decompression Sickness: A Review			5. FUNDING NUMBERS PE: 62202F PR: 7930 TA: 18 WU: 01	
6. AUTHOR(S) Zahid M. Sulaiman Andrew A. Pilmanis Robert B. O'Connor F. Wesley Baumgardner				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Armstrong Laboratory Crew Technology Directorate 2504 Gillingham Drive Suite 1 Brooks Air Force Base, TX 78235-5104			8. PERFORMING ORGANIZATION REPORT NUMBER AL/CF-TR-1994-0095	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)  Susceptibility to decompression sickness (DCS) is influenced by a multitude of factors. The purpose of this study was to determine the effect of age on susceptibility to DCS. A review of the literature on the relationship between age and susceptibility to DCS found an appreciable effect of age on group and individual susceptibility. Most of the studies reviewed were done during World War II and were limited to the age group between 18 and 30. However, Armstrong Laboratory (AL) DCS research database does include data for subjects over 40 years of age. The results from the AL DCS research database show that there was a significant increase in DCS risk for subjects over 42 years of age. They also show that susceptibility to DCS increases with age. There is generally a linear relationship between increasing age and increasing individual susceptibility to DCS..				
14. SUBJECT TERMS Decompression Sickness, DCS, age, susceptibility			15. NUMBER OF PAGES 20	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL	

## TABLE OF CONTENTS

	Page
Introduction .....	1
Susceptibility .....	1
Relationship between age and susceptibility to DCS .....	2
Summary .....	7
References .....	10

## LIST OF FIGURES

1. Susceptibility to decompression sickness related to age .....	4
2. Relation of bends to age .....	5
3. Susceptibility to DCS vs. age .....	6
4. Susceptibility to DCS vs. age (Altitude > 20K feet) .....	8
5. Susceptibility to DCS vs. age (Altitude = 29.5 K - 30 K feet) .....	9

## LIST OF TABLES

1. Susceptibility to Decompression Sickness of Various Age Groups .....	2
2. Age and Susceptibility to Decompression Sickness .....	3
3. Bends and Age .....	4
4. Susceptibility to DCS vs. Age .....	6
5. Susceptibility to DCS vs. Age for Altitude < 20,000 feet .....	7
6. Susceptibility to DCS vs. Age for Altitude > 20,000 feet .....	8
7. Susceptibility to DCS vs. Age for Altitude = 29.5K - 30K feet .....	9

or



on

By _____	
Distribution/ _____	
Availability Codes	
Dist	Avail and/or Special
A-1	

## ACKNOWLEDGMENTS

Several individuals made substantial contributions to prepare this report. We would like to gratefully acknowledge Mr Jau Tsau for his assistance in retrieving data from the Armstrong Laboratory DCS Research Database. A special thanks to Roberta Russell, Lt Col, USAF, BSC, Ret. and James T. Webb, PhD for their time in reviewing this report.

# **Relationship Between Age and Susceptibility to Decompression Sickness: A Review**

## **Introduction**

"In the period of over 100 years since the first recognition of decompression sickness (DCS), researchers in the field have asserted that age has an adverse effect on tolerance to altitude" (8). An extensive literature search on the relationship between age and susceptibility to DCS was conducted using databases from the Armstrong Laboratory (AL) DCS literature (DCSREF), the National Technical Information Service (NTIS), the Defense Technical Information Center (DTIC), Aerospace Medline, the Underwater Medicine Bibliography and several classical texts. The literature discussing the relationship between age and susceptibility to decompression sickness on both aviators and divers was reviewed.

According to Gray (12), certain individuals, when exposed repeatedly to a standard pattern of decompression, frequently develop DCS symptoms, whereas other individuals under the same conditions rarely do so, which indicates the existence of individual differences in susceptibility to decompression sickness. A given individual, when exposed repeatedly to a standard pattern of decompression may develop symptoms on some occasions, but not on others, indicating the existence of intra-subject variations in susceptibility to DCS.

Many authors have pointed out the variation in susceptibility between different individuals and have attempted to correlate this variability with age, weight or other physiological characteristics (8, 29, 31). Some authors have also pointed out that there may be considerable variation in the occurrence and severity of decompression sickness in the same individual at different times, and that this variability may be related to exercise (4, 6, 11, 17, 26), altitude of residence (7) and temperature (8, 13, 21, 33). Thus, there are a number of factors which may increase the susceptibility of an individual to DCS. The purpose of this report is to review age as one of the factors affecting susceptibility to DCS.

Stewart et al. (28, 29), have shown that the susceptibility of one individual to decompression sickness may be very different from that of another, presumably because of some difference in the physiology of the two individuals. Susceptibility to decompression sickness is undoubtedly influenced by a multitude of factors. This multiplicity of simultaneously operating factors tends to obscure the influence of any one factor. In such a situation, Gray (12) noted that the statistical methods of multiple and partial correlation are almost essential. The occurrence and severity of decompression sickness in a single individual may also be different on separate exposures, either because of changes in the environment or changes within the body itself not directly referable to environmental changes.

## **Susceptibility**

The susceptibility of a given subject at a given moment may be determined by exposing the subject at that moment to a standard decompression. The presence of symptoms indicates susceptibility, and the absence of symptoms, nonsusceptibility. The only direct and reliable measure of an individual's susceptibility consists of determining the percentage of a large number of repeated standard decompressions in which the individual develops symptoms.

A more relevant procedure than the above is the measurement of group susceptibility. This metric may be accomplished directly and quantitatively by determining the percentage of a large number of subjects who develop symptoms during a single standard decompression. There are two important characteristics of this measurement of group susceptibility. First, it is reliable in the sense that a repetition of the measurement on a given very large group will yield only random variation within rather narrow limits. Second, it is numerically equivalent to the mean of the individual susceptibilities of the subjects composing the large group.

## Relationship Between Age and Susceptibility to DCS

Fryer (9) noted that a man of any age may be a good or a bad subject in the decompression chamber, but there is a very distinct relationship between age and susceptibility to decompression sickness in the population. He states that susceptibility to decompression sickness increases by nine-fold between the age groups 17-20 and 27-29 years. He pointed out that there is no good statistical evidence on older men, or on women of any age, but it is generally accepted that susceptibility continues to increase with advancing age.

Ever since Pol and Watelle (22) reported the first systematic study of caisson disease in 1854, age has been considered as a "potential" factor affecting susceptibility to decompression sickness. Catsaras (3), Snell (27) and von Schrotter (13) have presented figures implying a higher incidence of compressed air illness in older than in younger workers. This opinion was supported by studies on experimental compressed air illness reported by Hill et al (15) and Boycott et al (2). In the hypobaric field, previous reports (5, 9, 12, 19, 20, 28, 32) have concluded that there is an increased susceptibility to decompression sickness in older men. In 1944, Thompson (32) presented data on the relationship of decompression sickness susceptibility to age. The incidence of decompression sickness according to age groups from Thompson (32) is in Table 1, which shows the susceptibility to DCS for 1,347 men who had one to three runs in a low pressure chamber. Individuals experiencing any symptoms of DCS, regardless of severity, on one or more occasions were termed "susceptible." The study showed a linear relationship between age and susceptibility to decompression sickness.

**Table 1. Susceptibility to Decompression Sickness  
of Various Aircrew Age Groups (Thompson, 1944)**

Age in Years	Susceptible to Decompression Sickness		Not Susceptible to Decompression Sickness		Total
	# of Subjects	Percent	# of Subjects	Percent	
18 to 19	65	50.00	65	50.00	130
20 to 21	204	55.28	165	44.72	369
22 to 23	187	57.72	137	42.28	324
24 to 25	123	61.19	78	38.81	201
26 to 27	75	58.14	54	41.86	129
28 to 29	60	62.50	36	37.50	96
30 to 31	35	74.47	12	25.53	47
32 to 33	28	70.00	12	30.00	40
34 to 35	11	100.00	0	0.00	11
<b>Total</b>	<b>788</b>		<b>559</b>		<b>1347</b>

Gray (12) made extensive observations on the incidence of altitude decompression sickness in U.S. Army Air Corps trainees of various ages, chiefly from 18 to 28, during World War II. The results, shown in Table 2, uniformly reveal an increase in group susceptibility with



increase in age. The data are from a total of 52,313 subjects reported by six independent sources (1, 12, 20, 24, 29, 32). Although the effect of age is apparent in each of the above sets of data, it is difficult to compare one set with another because the mean age varies from 21.7 to 24.6 years and the mean incidence of severe symptoms varies from 4.24 to 28.4 percent. Also, the altitude and duration of flight vary from one set to another.

**Table 2. Age and Susceptibility to Decompression Sickness (Gray, 1951)**

Source	Flight Pattern	Age		Number of Subjects	Severe Symptoms		
		Mean	Range		No.	%	Relative Susceptibility
R.C.A.F	35,000 feet for 4 hr	19.5	18-20	59	7	11.9	53
		22.5	21-23	78	17	21.8	96
		25.5	24-26	43	14	32.6	144
		28.5	27-29	18	7	38.9	171
	Totals and means	22.9		198	45	22.7	100
Randolph Field	3 hours at 38,000 feet	20.9	18-21	87	18	20.7	83
		22.5	22	93	23	24.7	99
		23.5	23	105	27	25.7	103
		25.0	24-25	222	63	28.4	113
		28.2	26-38	153	56	36.6	146
	Totals and means	24.6		660	187	28.4	114
Pensacola	35,000 feet for 40 min, then 40,000 ft for 10 min.	21.6	19-22	455	23	5.06	61
		24.0	23-24	312	27	8.65	105
		26.0	25-26	179	38	15.50	188
	Totals and means	23.2		946	88	8.25	100
Kingman Field	3 hours at 38,000 feet	19.4	17.5-20.5	1266	45	3.55	61
		21.5	20.5-22.5	969	46	4.75	81
		25.0	22.5-28.5	932	67	7.19	123
	Totals and means	21.7		3167	158	4.99	85
Santa Ana	3 hours at 38,000 feet	20.8	19-21	1097	89	8.11	72
		22.9	22-23	987	118	11.96	106
		25.0	24-25	579	74	12.78	113
		27.0	26-27	507	76	14.99	133
	Totals and means	23.2		3170	357	11.26	100
Maxwell Field	1 hour at 30,000 feet, and 15 min. at 38,000 feet	19.3	18-19	11,718	387	3.30	72
		21.0	20-21	15,472	612	3.96	86
		23.3	22-24	10,672	539	5.05	110
		26.7	25-30	6310	334	5.29	115
	Totals and means	22.0		44,172	1872	4.24	93

In Figure 1, relative susceptibility is plotted against age for each of the six sets of data. The 23 points describe a reasonably straight line. From this linear relationship, Gray (12) developed an equation to determine relative susceptibility to DCS with respect to age.

$$\text{Relative susceptibility} = 10.8 (\text{age}) - 145.$$

This regression equation reveals that the relative susceptibility increases by 10.8 % points for each year increase in age, over the range of 18 to 28 years. These results suggest an appreciable effect of age on group susceptibility to altitude decompression sickness.



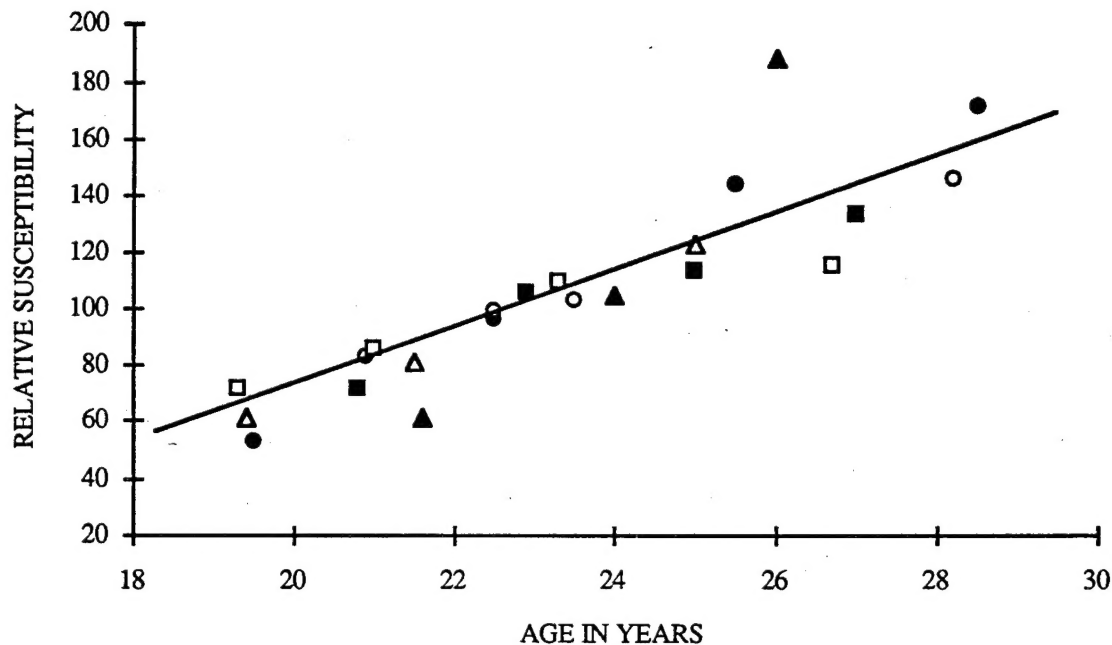


Figure 1. Susceptibility to decompression sickness related to age (Gray, 1951)

Motley, Chinn and Odell (20) found a much less striking variation with age, as illustrated in Table 3. They studied 68,422 trainees, and found over 9,500 cases of bends. The difference in percentage of bends between ages 18 and 29 was only 4%. The percentage in those age 30 actually dropped to 5.2%, as compared with 9.4% for age 18. However, the number of subjects in the 30-year age group was very small compared to that for 18. When data for all subjects over age 30 were analyzed, the percentage of bends rose to 20.1%.

Table 3. Bends and Age (Motley, 1945)

Age	Number of Subjects	Percentage of Bends						Total	Bearable/Unbearable
		Grade I	Grade II	Grade III	Grade IV	Bearable (1 & 2)	Unbearable (3 & 4)		
18	2355	2.3	4.6	2.3	0.2	6.9	2.5	9.4	2.8
19	9363	2.7	5.8	2.9	0.6	8.5	3.5	12.0	2.4
20	8250	3.5	6.3	3.5	0.5	9.5	4.0	13.8	2.5
21	7222	2.8	5.8	3.5	0.4	8.6	3.9	12.5	2.2
22	4736	2.7	6.7	4.3	0.6	9.4	4.9	14.3	1.9
23	3580	2.3	5.8	4.3	0.6	8.1	4.9	13.0	1.6
24	2356	2.4	6.3	4.7	0.9	8.7	5.6	14.3	1.6
25	2229	2.5	7.6	5.1	0.7	10.1	5.8	15.9	1.7
26	2081	2.3	7.1	4.6	0.5	9.4	5.1	14.5	1.8
27	1571	2.7	7.9	3.9	0.8	10.6	4.7	15.3	2.3
28	155	3.2	3.9	3.2	2.5	7.1	5.7	12.8	1.2
29	59	3.3	6.7	1.7	1.7	10.0	3.4	13.4	2.9
30	74	1.0	2.1	2.1	0	3.1	2.1	5.2	1.5
Over 30	141	4.2	7.6	6.9	1.4	11.8	8.3	20.1	1.4

Reports from other authors (5, 9, 12, 32) show two to six times as many bends in men aged 25 - 27 as in those 18 - 19 years of age, although a linear increase in susceptibility to DCS

among the age group 18 - 25 was observed. However, the differences were far less than those reported by other authors (5, 9, 12, 32). An interesting observation was the disproportionate rise of the more severe bends among older men, as shown in Figure 2. The ratio of bearable to unbearable bends falls from 2.5 in the youngest to 1.5 in the oldest group.

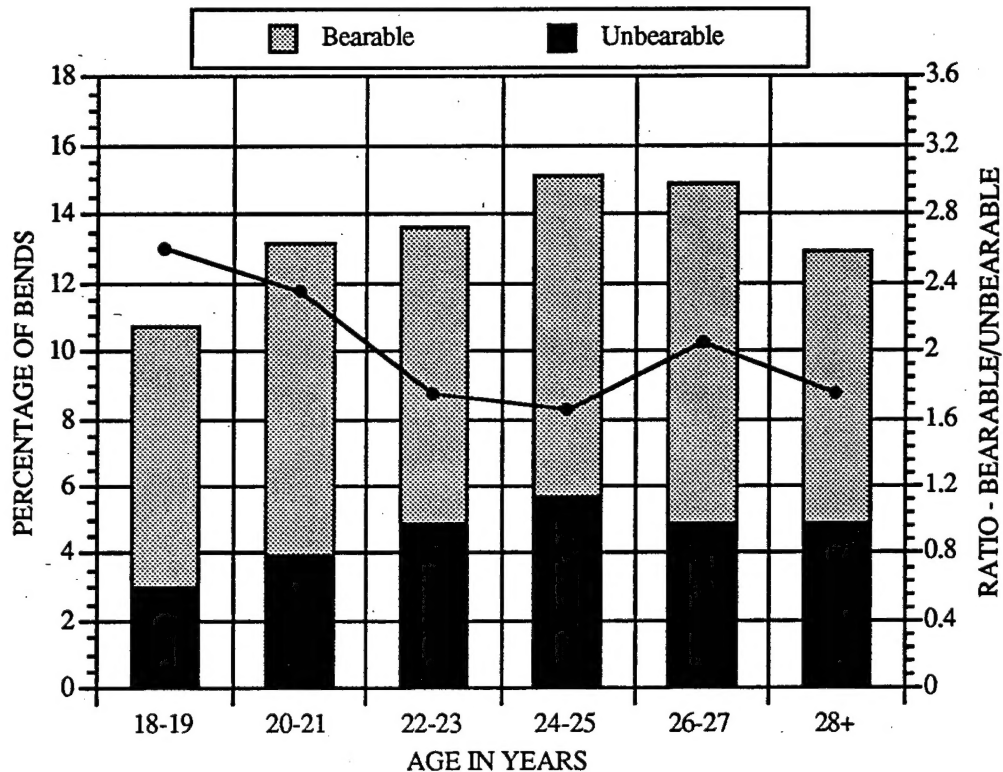


Figure 2. Relation of Bends to Age (Motley, 1945)

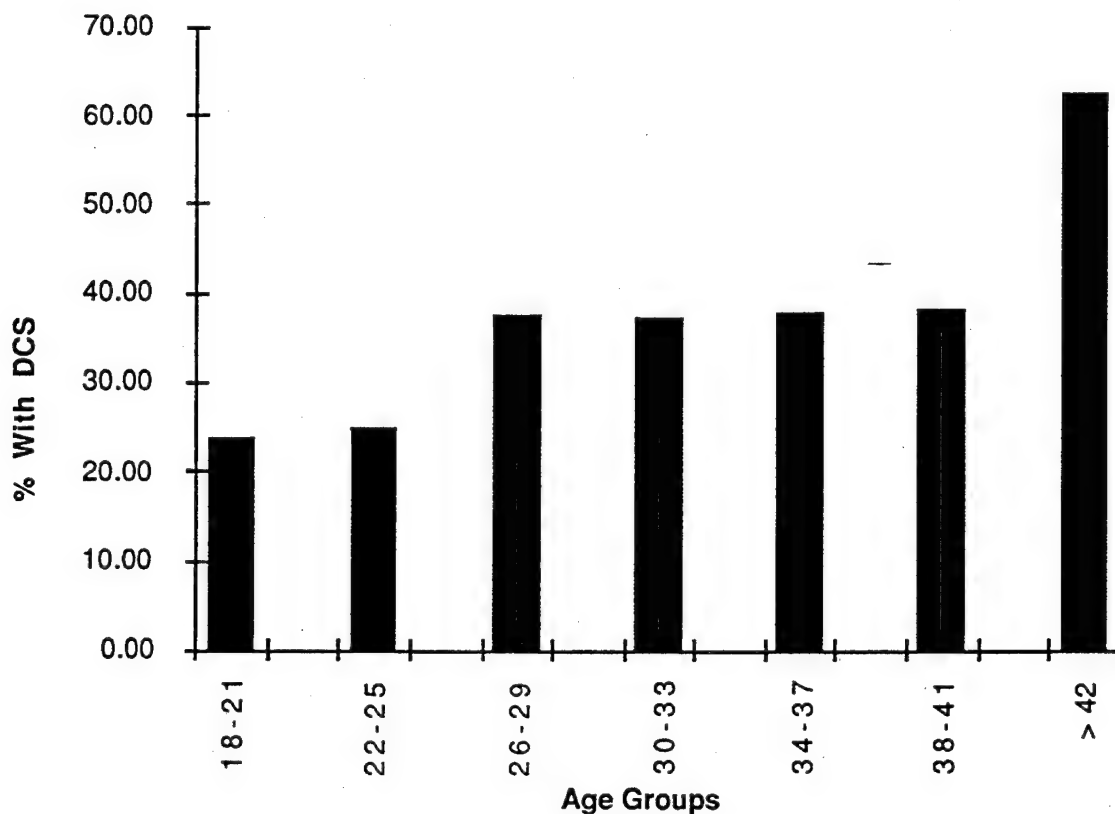
The majority of studies discussed thus far were conducted during World War II or shortly thereafter. More recent studies by Lo and O'Kelly (18), Smead et al. (25) and Webb et al. (34) also concluded that increasing age increases susceptibility to DCS. However, Kumar et al. (16) found no significant effect of age on susceptibility to DCS. Furthermore, all of these studies used a small number of subjects and were not originally designed to investigate age as a factor in DCS susceptibility. Therefore, the findings reported should be generalized with caution.

In this study we also examined our own Armstrong Laboratory (AL) DCS Research Database for a relationship between age and susceptibility to decompression sickness. Table 4. and Figure 3. contain data on 1,299 subjects exposed between October 1983 to March 1994 for 4 to 8 hours at various altitudes in a hypobaric chamber. Individuals experiencing any symptoms of decompression sickness, regardless of severity, on one or more occasions are termed 'susceptible'. The results show an increasing susceptibility to decompression sickness with age approximately of the order of three-fold comparing the age groups 18-21 with over 42 years of age. The results show that there is a significant increase in DCS risk for subjects over 42 years of age than among younger age groups (chi-square= 36.1,  $P < .001$ ). In contrast to data cited earlier, an interesting observation is that there is no major change in susceptibility to DCS for age groups from 26 through 41 years.

**Table 4. Susceptibility to DCS Versus Age\***

AGE GROUPS	Susceptible to Decompression Sickness		Not Susceptible to Decompression Sickness		TOTAL
	# of Subjects	Percent	# of Subjects	Percent	
18-21	28	23.53	91	76.47	119
22-25	71	24.74	216	75.26	287
26-29	135	37.60	224	62.40	359
30-33	89	37.24	150	62.76	239
34-37	55	37.93	90	62.07	145
38-41	42	38.18	68	61.82	110
> 42	25	62.50	15	37.50	40
<b>Total</b>	<b>445</b>		<b>854</b>		<b>1299</b>

\* from Armstrong Laboratory DCS Research Database (1983-1994).



**Figure 3. Susceptibility to DCS of various age group**

To determine if the differences in susceptibility between the youngest and oldest age groups could be a function of their exposure altitude, the data from the AL DCS Research Database were analyzed by age group for exposures above and below 20,000 feet. Table 5. shows data from 420 subjects whose exposures were less than 20,000 feet.

**Table 5. Susceptibility to DCS Vs Age (Altitude < 20,000 feet)\***

AGE GROUPS	Susceptible to Decompression Sickness		Not Susceptible to Decompression Sickness		TOTAL
	# of Subjects	Percent	# of Subjects	Percent	
18-21	1	2.17	45	97.83	46
22-25	1	0.93	107	99.07	108
26-29	1	0.94	105	99.06	106
30-33	2	2.63	74	97.37	76
34-37	0	0.00	41	100.00	41
38-41	1	3.85	25	96.15	26
> 42	2	11.76	15	88.24	17
<b>Total</b>	<b>8</b>		<b>412</b>		<b>420</b>

Table 6 and Figure 4 show the incidence of decompression sickness on 880 subjects who were exposed to altitude greater than 20,000 feet for 4 to 8 hour and prebreathed from 0 to 2 hours and 15 minute. Figure 4. show an identical trend, that there is a significantly increased susceptibility to DCS risk among those over 42 years of age compared with those in much younger age groups (chi-square= 32.6,  $P < 0.001$ ). It also show that there is approximately of the order of three-fold increase in susceptibility to DCS between the age group 18-21 with over 42 years of age. Again, there is no major change in susceptibility to DCS for the age groups between 26 to 41 years.

We also separately analyzed a subset of data on 111 subjects who had been exposed to an altitude of 29,500 - 30,000 feet. Prior to exposure, they all prebreathed 100% oxygen for one hour. Subjects completed at least 4 hours at simulated altitude, during which time they performed light to moderate exercise. These results, illustrated in Figure 5. and Table7, also show that there is a greater increase in susceptibility to DCS among those over 42 years of age than those in younger age groups.

## Summary

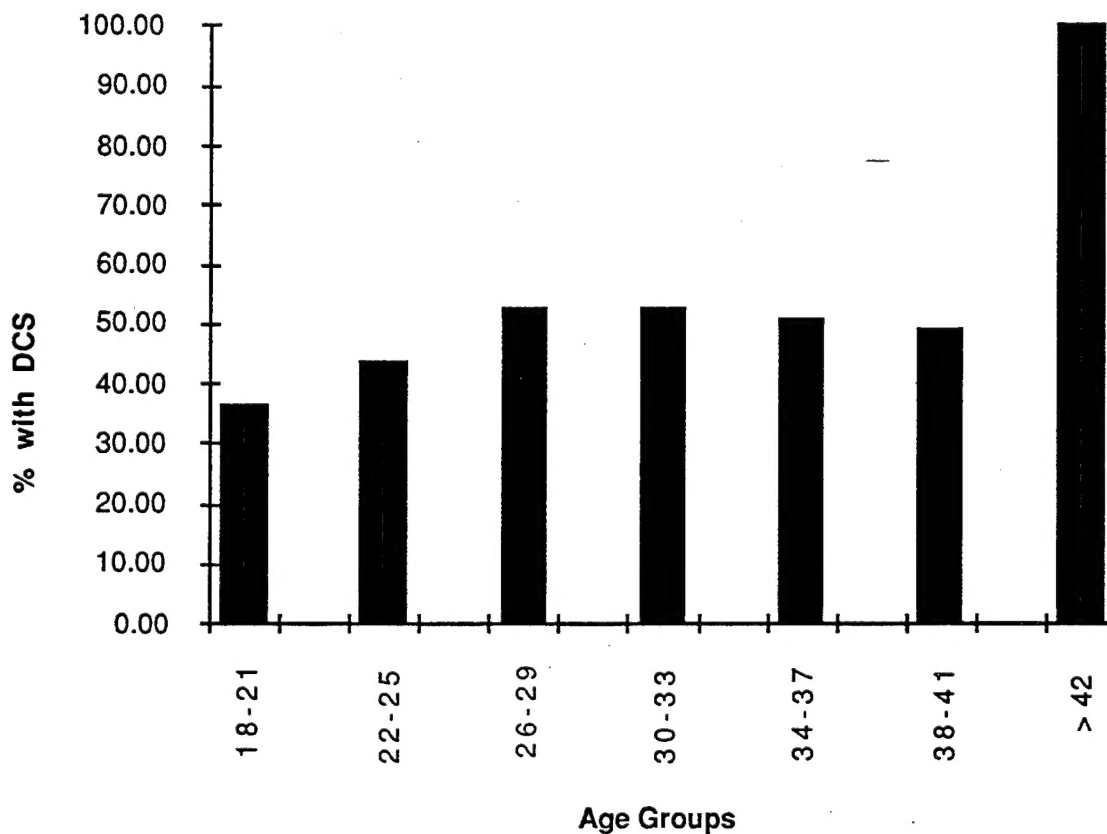
Decompression sickness affects some people more frequently than others. Group susceptibility also varies from time to time. A review of the literature on the relationship between age and susceptibility to DCS found an appreciable effect of age on group and individual susceptibility. There are other constitutional factors that are involved in the incidence of decompression sickness, such as time of day, atmospheric condition, exercise, fluid intake, weight, height and gender. However, some studies demonstrated a minimal effect of age and susceptibility to DCS. Furthermore, most of the studies reviewed were done during World War II and were limited to the age group between 18 and 30. However, the AL DCS Research Database, containing data from 1983 to 1994, does include data for subjects over 40 years of age. The results from the AL DCS Research database shows that there is a significant increase in DCS risk for subjects over 42 year of age compare to younger age group (chi-square= 36.1,  $P < .001$ ). It also

shows that susceptibility to DCS increases with age. In conclusion, there is generally a linear relationship between increasing age and increasing individual susceptibility to DCS.

**Table 6. Susceptibility to DCS vs Age (Altitude > 20,000 feet)\***

AGE GROUPS	Susceptible to Decompression Sickness		Not Susceptible to Decompression Sickness		TOTAL
	# of Subjects	Percent	# of Subjects	Percent	
18 - 21	27	36.49	47	63.51	74
22 - 25	78	43.58	101	56.42	179
26 - 29	133	52.57	120	47.43	253
30 - 33	86	52.76	77	47.24	163
34 - 37	53	50.96	51	49.04	104
38 - 41	41	48.81	43	51.19	84
> 42	23	100.00	0	0.00	23
<b>Total</b>	<b>441</b>		<b>439</b>		<b>880</b>

\* from Armstrong Laboratory DCS Research Database (1983-1994)



**Figure 4. Susceptibility to DCS of various age group at altitude > 20,000 feet**

Table 7. Susceptibility to DCS vs Age (Altitude = 29.5K - 30K feet)\*

AGE GROUPS	Susceptible to Decompression Sickness		Not Susceptible to Decompression Sickness		TOTAL
	# of Subjects	Percent	# of Subjects	Percent	
18 - 21	3	30.00	7	70.00	10
22 - 25	18	52.94	16	47.06	34
26 - 29	21	65.63	11	34.38	32
30 - 33	9	64.29	5	35.71	14
34 - 37	10	90.91	1	9.09	11
38 - 41	4	57.14	3	42.86	7
> 42	3	100.00	0	0.00	3
Total	68		43		111

\* from Armstrong Laboratory DCS Research Database (1983-1994)

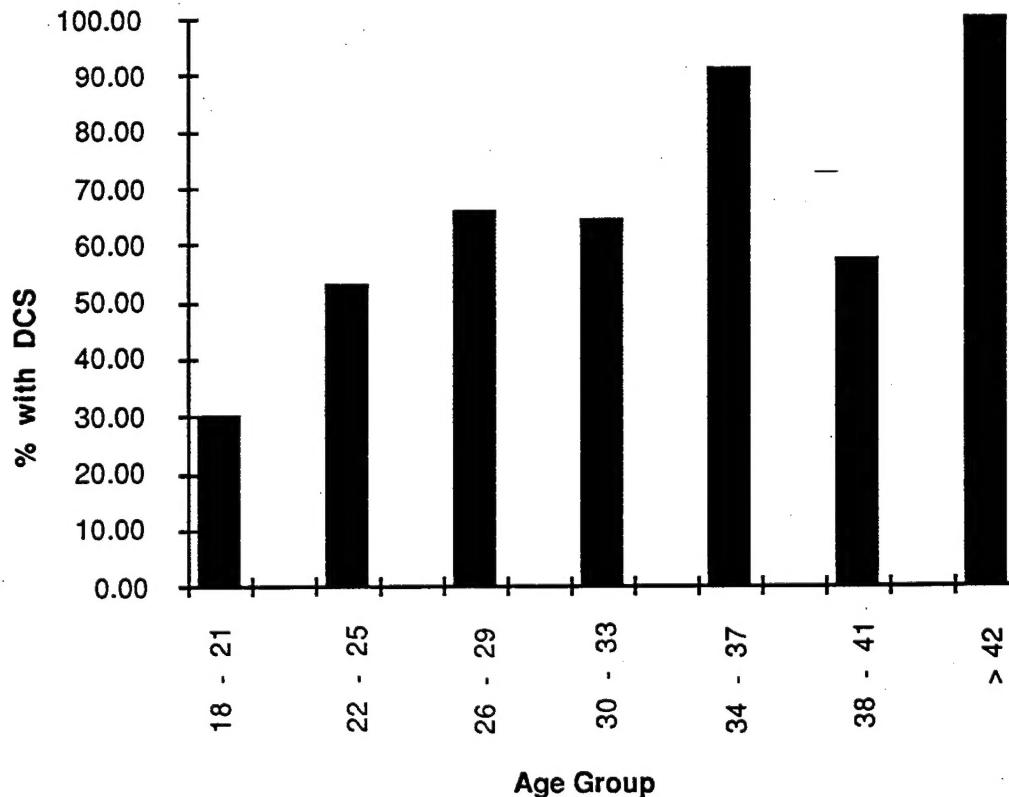


Figure 5. Susceptibility to DCS of various age group at altitude = 29.5K - 30K feet

## References

1. Altitude Training Unit, Santa Anna, California.
2. Boycott AE et al. The prevention of compressed air illness. *J Hyg* 1908,18:197-206.
3. Catsaras M. Reserches cliniques et experimentales sur les accidents survenant par l'emploi des scaphandres. Bureaux du progres Medical. Paris. 1890.
4. Cook SF, Williams OL, Lyons WR and Lawrence JH. A comparison of altitude and exer-cise with respect to decompression sickness. C.A.M. Report No. 245. January 1944.
5. Cotes JE and Gronow DGC. Influence of age and weight upon the incidence of decompression sickness in personnel bends- tested at the RAF I.A.M. between 1943 and 1952. I.A.M. Report No. FPRC 795. June, 1952.
6. Ferris EB et al. The importance of straining movements in electing the site of the bends. C.A.M. Report No. 121. February, 1943.
7. Fraser AM. The effect of altitude of residence on the incidence of decompression sickness. Royal Canadian Air Force, Regina. June, 1943.
8. Fraser AM and Rose B. The effect of low temperature on decompression sickness. Proceedings of the twelfth Meeting of the Associate Committee on Aviation Medical Research, National Research Council of Canada; January, 1942.
9. Fryer DI. Subatmospheric decompression sickness in man. 1969.
10. Fryer DI and Roxburgh HL. Decompression sickness. A Textbook of Aviation Physiology. Chap 8, edited by JA Gilles, 1965.
11. Gray JS. Aeroembolism induced by exercise in cadets at 23,000 feet. C.A.M. Report No. 260. January, 1944.
12. Gray JS. Constitutional factors affecting susceptibility to decompression sickness. Chap 7 in Fulton, JF. (Ed.);1951.
13. Griffin DR and et al. The effects of cold and rate of ascent on aeroembolism. C.A.M. Report No. 174. June, 1944.
14. Heller R, Mager W and von Schrotter H. *Luftdruckerkrankungen*. Wein, Alfred Holder. 2:1900.
15. Hill L et al. Caisson sickness and the physiology of work in compressed air. Edward Arnold. xi: 255 pp, 1912.
16. Kumar KV and et al. Epidemiology of decompression sickness under simulated space extravehicular activities. *Aviat Space Environ Med*; 64:1032-39, 1993.
17. Larrabee MG et al. Decompression sickness during exposures to 38,000 feet accompanied by exercise. Evaluation of a classification procedure. Univ. of Pennsylvania. Report No. C.A.M. 137. June, 1943
18. Lo WK and O'Kelly FJ. Health experience of compressed air workers during construction of the mass transit railway in Hong Kong. *J Soc Occup Med*; 37:48-51, 1987.
19. Morant GM. Results of tests in a decompression chamber of 610 flying personnel. RAF I.A.M. Report No. FPRC 793. June, 1952.
20. Motley HL et al. A studies of bends. *J Aviat Med* 1945, 16:210-34.
21. Nims LF, Clarke RW and et al. Temperature and decompression sickness. C.A.M. Report No. 136. May, 1943.
22. Pol B and Watelle TJ. Memoire sur les effect de la compression de lair appliquee au creusement des puits a houille. *Ann Hyg Publ* 1:241- 279, 1854.
23. Rivera C. Decompression sickness among divers: an analysis of 935 cases. Navy Experimental Diving Unit Research. Report No. 1-63, 1963.



24. School of Aviation Medicine, Pensacola. Incidence of decompression sickness in the classification of aviation personnel. C.A.M. Report No.88. September, 1942.
25. Smead KW et al. Decompression sickness and venous gas emboli at 8.3 psi. 24th Annual SAFE Symposium Proceedings. 196-9;1987.
26. Smith HW, Stewart CB and McAlpine HA. The effect of mild exercise on the incidence of decompression sickness on consecutive daily ascent to 35,000 feet. Royal Canadian Air Force, Regina. May, 1942.
27. Snell EH. Compressed air illness. Lewis HK. London, 1896.
28. Stewart CB and et al. A study of decompression sickness. Observations on 6,566 men during 16,293 exposure to simulated altitude of 35,000 feet. Royal Canadian Air Force, Halifax. March, 1943.
29. Stewart CB, Smith HW, McAlpine HA, Warwick OH and Manning GW. The incidence of decompression sickness on consecutive daily ascent to 35,000 feet. National Research Council of Canada. July, 1942.
30. Summit JK and et al. Review and analysis of cases of decompression sickness occurring under pressure. Navy Experimental Diving Unit. Report No. 12-71; December, 1971.
31. Thompson JW and Brett JR. Further studies on a prophylactic treatment for decompression sickness. National Research Council of Canada. March, 1942.
32. Thompson JW et al. Relationship of certain factors to the incidence of decompression sickness. Report No. C 2064, April, 1944.
33. Waters ET. Application to low temperature of selection at room temperature for resistance to decompression sickness. Royal Canadian Air Force, Toronto. June 1943.
34. Webb JT et al. Blood factors and venous gas emboli: surface to 429 mmHg (8.3 psi). Undersea Biomed Res:15(2); 107-21, 1988.
35. Wise DA. Constitutional factors in decompression sickness. USN Experimental Diving Unit. April, 1963.

#### **Additional References:**

- Bassett BE. Twelve year survey of the susceptibility of women to altitude decompression sickness. AsMA Ann. Sci. Mtg. Preprints. 12-3; 1980.
- Behnke AR. New approaches to medical aspects of work in compressed air. J Occup Med 11: May 1969, 259-72.
- Doll RE and Berghage TE. Interrelationships of several parameters of decompression sickness. US Navy Diving Unit. Report No. 7-65. March, 1967.
- Kumar KV et al. Time to detection of circulating micro-bubbles as a risk factor for symptoms of altitude decompression sickness. Aviat Space Environ Med; 63:961-64, 1992.
- Lam TH and Yau KP. Analysis of some individual risk factors for decompression sickness in Hong Kong. Undersea Biomed Res:16(4), 283-92, 1989.
- Walder DN. The prevention of decompression sickness. The Physiology and Medicine of Diving and compressed air work. by Bennett & Elliott, 2 ed, 1975.
- Weien RW and Baumgartner N. Altitude decompression sickness: Hyperbaric therapy results in 528 cases. Aviat Space Environ Med;61:833-36, 1990.
- West VR and et al. A review of the influence of physical condition parameters on a typical aerospace stress effect: decompression sickness. Bio-Technology, Inc. USN ONR TR-AD -453. June, 1973.
- Zwengelberg KM et al. Decompression sickness in women divers. Undersea Biomed Res:14(4);311-17,1987.